CLASSIFICATION OF WATER QUALITY USING ARTIFICIAL NEURAL NETWORK

KHADIJAH BINTI SULAIMAN

A thesis submitted in
fulfillment of the requirement for the award of the
degree of Master of Civil Engineering

Faculty of Civil Engineering and Built Environment
Universiti Tun Hussein Onn Malaysia

FEBRUARY 2020

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

For my beloved Mother, Fatimah Binti Ahmad,

My beloved person, Hairudin bin Munip,

My relatives and to my all friends,

My beloved supervisor, Assoc.Prof Ts. Dr. Lokman Hakim bin Ismail,

Thank you so much for your endless support, advices and encouragements. I couldn’t have completed this thesis without all of you. Thank you so much.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ACKNOWLEDGEMENT

Firstly, I would like to thank my parents and loved ones who had sacrificed so much and never tired of giving a boost and encouragement for me to continue to be successful in life in this world and the hereafter.

I also want to say a big thanks and appreciation to my supervisor, Assoc.Prof Ts. Dr. Lokman Hakim bin Ismail who work tirelessly to provide guidance, advice and insights for this research to be successfully done together.

Not to forget also to lecturers and colleagues who are directly and also indirectly involved to assist and provide support to ensure the success of this project. I thank them and may Allah s.w.t bless you all.

And last but not least, I would to thank the Ministry of Higher Education (MOHE) and Universiti Tun Hussein Onn Malaysia (UTHM) for financial and technical support. This study had been supported by Fundamental Research Grant Scheme (FRGS) Vot. 1524.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

Deterioration in water quality has triggered many countries to initiate serious mitigation efforts because it is essential to prevent and control water quality pollution and to implement regular monitoring programmes to preserve the environment. Hence, the water quality index (WQI) developed by Department of Environment (DOE) Malaysia has been used to classify water quality in Malaysia for the past few decades. However, another method has emerged for classifying water quality, for example soft computing approach. Therefore, this research aims to use the artificial neural network (ANN) algorithm to classify water quality at Pontian Kechil, Batu Pahat and Muar river. Concentrations of pH, suspended solids (SS), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), and ammoniacal-nitrogen (NH_3-N) were measured in situ and via laboratory analysis. Concentrations of these six parameters were used in the mathematical equation of the DOE-WQI technique and as input variables in the ANN database system. Based on the average WQI values of 35 stations for each river, it is shown that Pontian Kecil and Batu Pahat river were categorised in class III with WQI values of 71.2 and 71.5 respectively. Meanwhile, Muar river were categorised in class II with WQI values of 76.8. The performance of ANN model was identify based on the classification accuracy, sensitivity, precision, and root mean square error (RMSE). Then, the model performance was compared with the k-NN and Decision Tree models. The results obtained after training and testing the network showed that ANN performed better than to k-NN and Decision Tree model with the values of accuracy, sensitivity, precision and RMSE is 95.24%, 93.51%, 94.43% and 0.207 respectively. The ANN produced highly accurate water quality classification. In addition, it is more flexible than existing approaches and can be implemented easily and quickly.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRAK

Kemerosotan kualiti air telah mencetuskan permulaan usaha pengurusan yang serius dalam kalangan banyak negara. Oleh itu, pencemaran kualiti air perlulah sentiasa dikawal dan dicegah, selain pemantauan secara berkala perlu dilaksanakan. Teknik yang biasa digunakan selama beberapa dekad yang lalu bagi mengklasifikasikan kualiti air di Malaysia adalah indeks kualiti air (WQI) yang dibangunkan oleh Jabatan Alam Sekitar (JAS) Malaysia. Namun begitu, terdapat kaedah lain untuk mengklasifikasikan kualiti air iaitu dengan menggunakan teknik pengkomputeran lembut. Justeru itu, kajian ini bertujuan untuk menyiasat kaedah untuk mengklasifikasikan kualiti air berdasarkan rangkaian neural buatan di sungai Pontian Kechil, Batu Pahat dan Muar. Kepekatan bagi parameter kualiti air diperolehi melalui pengukuran '*in-situ*' dan analisis makmal seperti pH, pepejal terampai (SS), oksigen terlarut (DO), keperluan oksigen kimia (COD), keperluan oksigen biologi (BOD), dan ammoniacal nitrogen (NH_3-N). Parameter ini digunakan dalam persamaan matematik bagi teknik DOE-WQI dan digunakan sebagai pemboleh ubah dalam sistem pangkalan data rangkaian neural buatan. Berdasarkan nilai purata WQI untuk 35 stesen menunjukkan sungai Pontian Kechil dan Batu Pahat dalam kategori kelas III dengan nilai WQI 71.2 dan 71.5 masing-masing. Manakala, sungai Muar dalam kategori kelas II dengan nilai WQI 76.8. Prestasi model ANN dikenalpasti berdasarkan ketepatan klasifikasi, kepekaan, kepersisan dan RMSE. Kemudian, prestasi model dibandingkan dengan model k-NN dan Decision Tree. Hasil yang diperolehi selepas latihan dan ujian rangkaian menunjukkan bahawa ANN menghasilkan prestasi yang lebih baik berbanding k-NN dan Decision Tree dengan nilai ketepatan klasifikasi, kepekaan, kepersisan dan RMSE adalah 95.24%, 93.51%, 94.43% dan 0.207 masing-masing. ANN menunjukkan klasifikasi kualiti air dengan kadar ketepatan yang tinggi. Kaedah ini adalah lebih fleksibel daripada pendekatan sedia ada dan boleh dilaksanakan dengan mudah dan cepat.

CONTENTS

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

SYMBOLS AND ABBREVIATIONS

ANN	-	Artificial neural network
BOD	-	Biological oxygen demand
COD	-	Chemical oxygen demand
DO	-	Dissolve oxygen
DOE	-	Department of environment
NH_3-N	-	Ammoniacal Nitrogen
RMSE	-	Root mean square error
SS	-	Suspended solids
WQI	-	Water quality index

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF APPENDICES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Background of research

Water quality refers to the extent of which water is safe for human consumption and for perpetuating the life of all living things on Earth. In broader terms, the term incorporates the quality of irrigation, recreation, and the ability to sustain marine life (Rahaman *et al*., 2016). Water is essential for maintaining a balance between human biodiversity and the ecosystem; hence, good water quality is paramount (Najah *et al*., 2009). Recent concern over water quality has emerged, relating to substances in water which could harm human beings and the environment. A significant change in the quality of water resources could emerge due to urban development, agricultural and industrial activities (Zeinalzadeh & Rezaei, 2017). In addition, Huang *et al*. (2013) mentioned that human activities could cause a devastating impact on water bodies through uncontrolled land use for urbanisation, deforestation, industrialisation and farming activities. These activities may result in environmental problems, for example, eutrophication and changes in biological structure (Araújo *et al*., 2017). In addition, numerous chemical substances delivered to rivers and coastal areas could also cause harm to humans and the environment.

The physicochemical components in water such as dissolved solids, turbidity, acidity, alkalinity, and suspended solids make up the composition of water. Sage *et al*. (2015) stated that the above components, if discharged, could accumulate in the water sediment. Numerous contaminants accumulate in the river sediment and reach concentrations higher than those in the surrounding water. As a result, aquatic life faces a higher risk of exposure to the contaminants.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

In Malaysia, DOE (2010) recorded 20,348 water pollution point sources in 2010 consisting, sewage treatment plants (49.27%), manufacturing industries (44.57%), animal farms (3.70%) and agro-based industries (2.46%). At present, water from rivers in Malaysia is not safe for human consumption due to its questionable quality.

In addition, rapid trading activities in cities situated in the West Coast of Peninsular Malaysia have caused Straits of Melaka (Figure 1.1) to become one of the most polluted waterways. The major sources of pollution come from oil exploration activities, oil waste disposal and oil spills from commercial vessel collision. Once oil spills into the water, current can transport the oil far from its origin, further causing significant problems for the river. Table 1.1 shows the status of river water quality Malaysia in 2017 in particular for western areas of Johor which is nearby to the Straits of Melaka.

Figure 1.1: Straits of Malacca

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Table 1.1: Water quality 2017 (DOE, 2017)

Location	WQI value	Class	Category
Batu Pahat river	61	III	Polluted
Benut river	69	III	Polluted
Pontian Besar river	60	III	Polluted
Pontian Kechil river	72	III	Polluted
Rambah river	66	III	Polluted
Muar river	80	II	Slightly polluted

Extensive water quality assessment in Malaysia started in 1985, with advancement of water quality criteria and benchmarks based on the water quality index (WQI) introduced by the DOE. The objective of the assessment was centred on an appropriate methodology for water quality assessment to ensure good long-term water quality. A reasonable way to assess water quality is to categorise the river or river segments according to five water quality classes i.e. class I, II, III, IV and V. These classes relate to water quality targets or standards required to ensure that the water sources are beneficial and safe for use (Ismail, Sulaiman & Karim, 2014). The beneficial uses of water include as residential water supply, fisheries and domestic livestock drinking water as well as recreational and agricultural uses. The DOE introduced the national water quality standards (NWQS) to enable the assessment of any potential deterioration in water quality and to improve upon current water quality standards (Naubi *et al*., 2016). With the introduction of NWQS, river waters are assessed at a perceived point along the river system. The evaluated water quality is classified and the most sustainable beneficial uses of water identified. The results of this assessment will help the government to plan and decide on zoning purposes such as lodging, industry and farming based on the suitability and accessibility of local water supply.

1.2 Problem statement

Malaysia is now a rapidly developing country in line with its vision to become a developed country by 2020. However, the rapid development has negatively affected the environment, particularly water quality (Najah *et al*., 2009). Water is a major natural resource for many sectors. Due to water being a sensitive and vulnerable resource, a variety of human activities could negatively impact its quality (Jiao *et al*., 2015), for example, the river water quality of western area in Johor state experienced

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

pollution due to agricultural activities such as oil palm plantation along riverside of Muar river as well as Batu Bahat and Pontian river. Meanwhile land use activities such as quarry and pig farms had affected the water quality of Batu Pahat river. In other hand, human activities such as fishing, industrial and tourism of Pontian river lead to deterioration of its water quality. Human activities on the ecosystem have been recognised as a major source of pollution. Deterioration in water quality has triggered many countries to initiate serious mitigation efforts.

This circumstance has created incredible pressure on the biological system, resulting in a decline of water quality and biodiversity, a loss of critical habitats and an overall decrease in the quality of life of the local inhabitants (Bastawrous & Hennig, 2014). Therefore, it is essential to prevent and control water quality contamination and to enforce standard checking programmes, which will contribute to the knowledge of temporal and spatial varieties as well as diagnosis of the current water quality (Barakat *et al*., 2016). Water quality changes with time and space, thus, consistent water quality measurement and investigations are important for the successful management of water quality. In water resource administration, water quality monitoring is an essential approach that must be taken. Despite the fact that it might cover numerous aspects, basically, the objectives of a water quality monitoring programme concern the preliminary evaluation of water quality in terms of concentration and pattern, standard classification and early warnings or detection of pollution (Yan *et al*., 2015).

Water contamination has become a serious issue such that numerous countries have implemented water quality monitoring programmes to supervise and reduce pollution effects to a minimum. However, the large volume of water quality information collected covers a comprehensive and diverse set of variables making interpretation increasingly troublesome (Read *et al*., 2017). While the process involving single variables is direct, complex multiple-variable processes are the opposite. These variables may have a more noteworthy effect if they exist in immense volumes. Although less effect may occur at less volume, the interaction between different variables could pose a severe issue.

In such conditions, it is important to choose the variables that show the condition of water quality (Karaman, 2013). For the most part, once the critical variables are chosen, their values are estimated in order to fit into a numerical or statistical formula. These equations are intended to deliver a single numerical value or index value ascertained from the observed water quality dataset. Therefore, an index

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

is a way to reduce a large amount of data down to its most straightforward shape that can holds only the most important significance for describing water quality (Tyagi *et al*., 2014). The water quality index (WQI) was designed to assess water according to its uses. The main idea of the WQI is to compare water quality variables (WQVs) with the water quality standard, so that the variables which exceeded the standard can be identified (Gazzaz *et al*., 2012).

The existing method for water quality classification in Malaysia is the classification based on DOE-WQI. However, there is another technique for water quality assessment that has been shown to be progressively versatile which works well with large volumes of data, yields fast results and makes it easy to assess water quality known as the soft computing technique. One of the techniques is artificial neural network (ANN) has shown good promise. Most water quality strategies rely upon 'pattern recognition', which is a significant strength of the ANN. Hence, ANN can help in the assessment and classification of water quality (Chu, Lu & Zhang, 2013).

Hence, this research aims to explore another method for classifying water quality rather than the DOE-WQI. This method is based on the concept of artificial neural network (ANN).

1.3 Objectives

The aim of this research is to investigate the classification of water quality using artificial neural network on selected rivers in western areas of Johor state. The water quality parameters are determined to achieve the goals of this research. The objectives of this research can be summarised as follows:

Objective 1: To determine the classes of water quality based on the DOE-WQI technique to set the target variables for artificial neural network.

Objective 2: To determine artificial neural network model performance based on classification accuracy, sensitivity, precision and root mean square error (RMSE).

Objective 3: To compare the performance of artificial neural network model with other classifier models, namely k-Nearest Neighbour (k-NN) and Decision Tree model.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.5 Scope and limitation of research

This research assessed and classified water quality using artificial neural network. Physical and chemical parameters were collected through several series of combination and continuous in-situ measurements and adaptive synoptic sampling carried out during low tide on six parameters which are dissolve oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), suspended solid (SS) and pH. These parameters were used in a mathematical equation provided by the DOE-WQI and used as a feeder for the input variables to ANN database system. As far as the input parameters are concerned, the water quality data and class category were defined as independent and dependent variables respectively. Both variables could alternatively be combined as input variables depending on the suitability of the algorithm. Based on a set of data collected from the sampling site, namely Pontian Kechil, Batu Pahat and Muar river were used to demonstrate the potential of the proposed classification model. The findings indicate that the proposed technique successfully harmonised inherent discrepancies and interpreted complex conditions. However, the limitation of this research is due to use of WQI where the six parameters used to ascribe water quality mostly based on the physio-chemical without consideration for coli indicators and heavy metal.

1.6 Significance of research

The output of this research provides a comprehensive water quality classification method. Besides that, it also identifies an additional factor that affects water quality which is the river discharge parameters. Furthermore, this research contributes to new knowledge, specifically, a practical approach to classification of water quality. On the other hand, this research also provides an understanding of how to use artificial neural network for classification of water quality. This classification model will be particularly useful for ecologists and environmentalists, as it will enable them to classify the water pollution level and take necessary precautions in advance. In addition, the classification model proposed in this research provides a relatively good correlation between the measured model and the classification model. This research

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

also demonstrated the effectiveness of the artificial neural network model in classifying water quality.

This research of ANN reveals hidden relationships in the historical data, thus facilitating the classification of water quality. This model could be used in parallel with a physics-based model to produce a new classification tool. It can also be used to identify important parameters, in turn, facilitating both selective physical and chemical monitoring and providing a quick water quality assessment method.

Finally, this research provides some opportunities for other researchers to explore the use of ANN as a classification model for water quality in the future.

1.7 Structure of thesis

This thesis is structured into five chapters. Chapter 1 presents the introduction, problem statement and objectives of the study as well as the scope, limitation and significance of study. Next, a review of related literature is presented in Chapter 2. The methodology of the study is discussed in Chapter 3, which shows the study area, the method of data collection, the classification of water quality using the DOE-WQI model and the determination of ANN model performance in classifying water quality. Chapter 4 presents the results of the water quality parameter obtained, the result of the water quality classification based on the DOE-WQI model, the result of ANN model performance and a comparison of the results with k-NN and Decision Tree classifier models. Lastly, Chapter 5 concludes this research and provides some suggestions for future research.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

Abdolmaleki, A. S., Ahangar, A. G. & Soltani, J. (2013). Artificial Neural Network (ANN) approach for predicting concentration of heavy metal in drinking water of Chahnimeh reservoir in Sistan-Balochistan, Iran. *Health Scope, 2(1),* pp. 31-38.

Afroz, R., Masud, M. M., Akhtar, R. & Duasa, J.B. (2014). Water pollution: Challenges and future direction for water resources management policies in Malaysia. *Environment and Urbanization ASIA, 5(1),* pp. 63-81.

Aggarwal C.C. & Reddy C.K. Data Clustering, *CRC Press, Taylor & Francis group*; 2014.

Ahmad, S., Kutty, A. A., Raji, F. & Saimy, I. S. (2015). Water quality classification based on water quality index in Sungai Langat, Selangor, Malaysia. *Jurnal Teknologi, 77(30),* pp. 139-44.

Akinbile, C.O., Yusoff, M. S., Talib, S.H.A., Hasan, Z.A., Ismail, W.R. & Sansudin, U. (2013). Qualitative analysis and classification of surface water in Bukit Merah Reservoir in Malaysia. *Water Science & Technology: Water Supply, 13(4),* pp. 1138-1145.

Al-Badaii, F., Shuhaimi, O. M. & Gasim, M. B. (2013). Water quality assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry*, 2013, pp. 1-10.

Al-Baidhani, J.H. & Alameedee, M.A. (2017). Prediction of water treatment plant outlet turbidity using Artificial Neural Network. *7(4),* pp. 1559-1565.

Al-Shayea, Q. K. (2011). Artificial neural networks in medical diagnosis. *International Journal of Computer Science Issues, 8(2),* pp. 150-154.

Amneera, W. A., Najib, N. W. A. Z., Yusof, S. R. M. & Ragunathan, S. (2013). Water quality index of Perlis River, Malaysia. *International Journal of Civil & Environmental Engineering, 13(2),* pp. 1-6.

Araújo, C. A., Sampaio, F. G., Alcântara, E., Curtarelli, M. P., Ogashawara, I. & Stech, J. L. (2017). Effects of atmospheric cold fronts on stratification and water quality of a tropical reservoir: Implications for aquaculture. *Aquaculture Environment Interactions*, *9*, pp. 385-403.

Areerachakul, S. (2013). The using artificial neural network to estimate of chemical oxygen demand. *International Journal of Chemical and Molecular Engineering*, *7(7)*, pp. 578-581.

Ariffin, M. & Sulaiman, S. N. M. (2015). Regulating sewage pollution of Malaysian rivers and its challenges. *Procedia Environmental Sciences*, *30*, 168-173.

Arman, N. Z., Said, M. I. M., Salmiati, Azman, S. & Hussin, M. H. M. (2013). Comparison between water quality index (WQI) and biological water quality index (BWQI) for water quality assessment: Case study of Melana River, Johor. *The Malaysian Journal of Analytical Sciences*, *17(2)*, pp. 224-229.

Asharuddin, M. S., Zayadi, N., Rasit, W. & Othman, N. (2016). Water quality characteristics of Sembrong dam reservoir, Johor, Malaysia. In *IOP Conference Series: Materials Science and Engineering*, *136(1)*, pp. 1-6.

Bala, R. & Kumar, D. (2017). Classification using ANN: A Review. *International Journal of Computational Intelligence Research*, *13(7)*, 1811-1820.

Ballantine, D. J., Hughes, A. O. & Davies, O. R. J. (2015). Mutual relationships of suspended sediment, turbidity and visual clarity in New Zealand Rivers. *Proceedings of the International Association of Hydrological Sciences*, *367*, pp. 265-271.

Barakat, A., El Baghdadi, M., Rais, J., Aghezzaf, B. & Slassi, M. (2016). Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. *International Soil and Water Conservation Research*, *4(4)*, pp. 284-292.

Bastawrous, M. & Hennig, B. (2014). Impacts of climate change on the future of biodiversity. *Ecology Letters*, 15(4), pp. 365-377.

Basu, J. K., Bhattacharyya, D. & Kim, T. H. (2010). Use of artificial neural network in pattern recognition. *International Journal of Software Engineering and its Applications*, *4(2)*, pp. 23-34.

Bhatnagar, A. & Devi, P. (2013). Water quality guidelines for the management of pond fish culture. *International Journal of Environmental Sciences*, *3(6)*, pp. 1980-2009.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Bilotta, G. S. & Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research, 42(12)*, pp. 2849-2861.

Biswas, S. K. & Mia, M. M. A. (2015). Image reconstruction using multi-layer perceptron (MLP) and support vector machine (SVM) classifier and study of classification accuracy. *International Journal of Scientific & Technology Research*, *4(2)*, pp. 226-231.

Borra, S. & Di Ciaccio, A. (2010). Measuring the prediction error. A comparison of cross validation, bootstrap and covariance penalty methods. *Computational Statistic and Data Analysis, 54(12)*, pp. 2976-2989.

Borvinskaya, E., Gurkov, A., Shchapova, E., Baduev, B., Shatilina, Z., Sadovoy, A. & Timofeyev, M. (2017). Parallel in vivo monitoring of pH in gill capillaries and muscles of fishes using microencapsulated biomarkers. *Biology Open*, *6(5)*, pp. 673-677.

Chang, K. H., Amano, A., Miller, T. W., Isobe, T., Maneja, R., Siringan, F. P. & Nakano, S. I. (2009). Pollution study in Manila Bay: Eutrophication and its impact on plankton community. *Interdisciplinary Studies on Environmental Chemistry - Environmental Research in Asia*, 261-267.

Chu, H. B., Lu, W. X. & Zhang, L. (2013). Application of artificial neural network in environmental water quality assessment. *Journal of Agricultural Science and Technology*, *15(2)*, pp. 343-356.

Darajeh, N., Idris, A., Truong, P., Abdul Aziz, A., Abu Bakar, R. & Che Man, H. (2014). Phytoremediation potential of vetiver system technology for improving the quality of palm oil mill effluent. *Advances in Materials Science and Engineering*, *2014(4)*, pp. 1-10.

Dawood, A. S., Hussain, H. K. & Hassan, A. (2016). Modeling of river water quality parameters using artificial neural network: A case study. *International Journal of Advances in Mechanical and Civil Engineering*, *3(5)*, pp. 51–55.

DOE. (2010). *Benchmarking River Water Quality Monitoring*. Department of Environment, Ministry of Natural Resources and Environment, Malaysia.

DOE. (2017). *Report of Environment Quality*. Department of Environment, Ministry of Natural Resources and Environment, Malaysia.

DID. (2009). *Manual for River Management Malaysia*. Department of Irrigation and Drainage, Malaysia.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Dodds, W. K. & Smith, V. H. (2016). Nitrogen, phosphorus, and eutrophication in streams. *Inland Waters*, *6(2)*, pp. 155-164.

Eluyode, O. S. & Akomolafe, D. T. (2013). Comparative study of biological and artificial neural networks. *European Journal of Applied Engineering and Scientific Research, 2(1),* pp. 36–46.

Emrani, S., Salehizadeh, S. A., Dirafzoon, A. & Menhaj, M. B. (2010). Individual particle optimized functional link neural network for real time identification of nonlinear dynamic systems. *5th IEEE Conference on Industrial Electronics and Applications*, IEEE. pp. 35-40.

García, S., Fernández, A., Luengo, J. & Herrera, F. (2010). Advanced nonparametric tests for multiple comparisons in the design of experiments in computational intelligence and data mining: Experimental analysis of power. *Information Sciences*, *180(10),* pp. 2044-2064.

Gazzaz, N. M., Kamil, M., Zaharin, A. & Juahir, H. (2012). Artificial neural network modelling of the water quality index for Kinta River (Malaysia) using water quality variables as predictors. *Marine Pollution Bulletin*, *64(11),* pp. 2409-2420.

Ghazali, R., Husaini, N. A., Ismail, L. H., Herawan, T. & Hassim, Y. M. M. (2014). The performance of a Recurrent HONN for temperature time series prediction. *International Joint Conference on Neural Networks (IJCNN)* IEEE. pp. 518-524.

Gour, S. & Gour, M. (2014). Neural network approach in water quality data analysis for the River Narmada. *Binary Journal of Data Mining & Networking*, *4(2)*, pp. 49-53.

Govorushko, S. (2007). Effect of human activity on rivers. *International Conference on River Basin Management*, *Basin water* (October), pp. 464-476.

Gyawali, S., Techato, K. & Yuangyai, C. (2012). Effects of industrial waste disposal on the surface water quality of U-tapao River, Thailand. *International Conference on Environment Science and Engineering, International Proceedings of Chemical, Biological and Environmental Engineering 3(2),* pp. 109-113.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Hamlat, A., Tidjani, A. E. B., Yebdri, D., Errih, M. & Guidoum, A. (2014). Water quality analysis of reservoirs within Western Algeria catchment areas using water quality index CCME WQI. *Journal of Water Supply: Research and Technology-AQUA, 63(4),* pp. 311-324.

Hasan, H. H., Jamil, N. R. & Aini, N. (2015). Water quality index and sediment loading analysis in Pelus River, Perak, Malaysia. *Procedia Environmental Sciences*, *30*, pp. 133-138.

Heydari, M., Olyaie, E. & Mohebzadeh, H. (2013). Development of a neural network technique for prediction of water quality parameters in the Delaware River, Pennsylvania. *Middle-East Journal of Scientific Research*, *13(10),* pp. 1367-1376.

Huang, J., Zhan, J., Yan, H., Wu, F. & Deng, X. (2013). Evaluation of the impacts of land use on water quality: A case study in the Chaohu Lake basin. *The Scientific World Journal*, pp. 1-8.

Islam, B. I., Musa, A. E., Ibrahim, E. H., Sharafa, S. A. A. & Elfaki, B. M. (2014). Evaluation and characterisation of tannery wastewater. *Journal of Forest Products & Industries, 3(3),* pp. 141-150.

Ismail, Z., Sulaiman, R. & Karim, R. (2014). Evaluating trends of water quality index of selected Kelang River tributaries. *Environmental Engineering & Management Journal (EEMJ)*, *13(1),* pp. 61-72.

Jaloree, S., Rajput, A. & Gour, S. (2014). Decision tree approach to build a model for water quality. *Binary Journal of Data Mining & Networking*, *4*, pp. 25-28.

Jioa, X., Teng, Y., Zhan, Y., Wu, J. & Lin, X. (2015). Soil heavy metal pollution and risk assessment in Shenyang District, Northeast China. *PLOSONE*, *10(5),* pp. 1-9.

Kamiński, K. & Mizerski, T. (2017). Application of artificial neural networks to the technical condition assessment of water supply systems. *Ecological Chemistry and Engineering*, *24(1),* pp. 31-40.

Kanu, I. & Achi, O. K. (2011). Industrial effluents and their impact on water quality of receiving rivers in Nigeria. *Journal of Applied Technology in Environmental Sanitation. 1(1),* pp. 75-86.

Karaman, H. G. (2013). Identifying uncertainty of the mean of some water quality variables along water quality monitoring network of Bahr El Baqar drain. *Water Science, 27(54),* pp. 48-56.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Khashei, M. & Bijari, M. (2010). Expert systems with applications an artificial neural network model for timeseries forecasting. *Expert Systems with Applications, 37(1),* pp. 479-489.

Khatri, N. & Tyagi, S. (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science, 8(1),* pp. 23-39.

Kumar, S. P., Verma, S. & Mahajan, B. V. (2015). Application of ANN model for the prediction of water quality index. *International Journal of Engineering Research and General Science, 3(1),* pp. 1-6

Liao, Y., Xu, J. Y. & Wang, Z. W. (2012). Application of biomonitoring and support vector machine in water quality assessment. *Journal of Zhejiang University Science B, 13(4),* pp. 327-334.

Liyanage, C. & Yamada, K. (2017). Impact of population growth on the water quality of natural water bodies. *Sustainability, 9(8),* pp. 1405.

Low, K.H (2007). Water Quality Study of Sungai Batu Pahat, Universiti Teknologi Malaysia, Master`s Thesis.

Lopez, A., Peña-Mendez, E. M., Vanhara, P. & Havet, J. (2013). Artificial neural network in medical diagnosis. *Journal of Applied Biomedicine, 11*, pp. 47-58.

Lu, J., Yuan, F. & Zhang, F. (2015). Use of SVM technique for comparison of water quality : A case study from China. *International Journal of Performability Engineering, 11(5),* pp. 473-480.

Maind, S. B. & Wankar, P. (2014). Research paper on basic of artificial neural network. *International Journal on Recent and Innovation Trends in Computing and Communication, 2(1),* pp. 96-100.

Mamun, A. A. & Zainudin, Z. (2013). Sustainable river water quality management in Malaysia. *IIUM Engineering Journal, 14(1),* pp. 29-42.

Mansourkhaki, A., Berangi, M. & Haghiri, M. (2018). Comparative application of radial basis function and multilayer perceptron neural networks to predict traffic noise pollution in Tehran roads. *Journal of Ecological Engineering, 19(1),* pp. 113-121.

Martinasek, Z., Hajny, J., & Malina, L. (2013). Optimization of power analysis using neural network. *International Conference on Smart Card Research and Advanced Applications.* Springer. pp. 94-107.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Maung, P. (2012). Augmented reality using a neural network. *Midwest Instruction and Computing Symposium (MICS)*. pp. 1-15.

Meng, X., Jia, M. & Wang, T. (2014). Neural network prediction of biodiesel kinematic viscosity at 313 K. *Fuel*, *121*, pp. 133-140.

Ming, L., Yan-Chun, L., Xin-Min, W. & Xiao-Gang, D. (2010). The application of GA-BP algorithm to intelligent diagnosis of coronary heart disease. *International Conference on Computer, Mechatronics, Control and Electronic Engineering*. IEEE. pp. 367-370.

Mohammadzadeh, A. & Mahdipour, N. (2012). Forecasting the cost of water using a neural network method in the municipality of Isfahan. *Journal of Optimization in Industrial Engineering*, *5(11)*, pp. 73-85.

Mustafa, M. R., Isa, M. H. & Rezaur, R. B. (2012). Artificial neural networks modelling in water resources engineering: Infrastructure and applications. *International Journal of Civil, Environmental, Structural, Construction, Architecture and Engineering*, *6(2)*, pp. 128-136.

Najah, A., Elshafie, A., Karim, O. A. & Jaffar, O. (2009). Prediction of Johor River water quality parameters using artificial neural networks. *European Journal of Scientific Research*, *28(3)*, pp. 422-435.

Naubi, I., Zardari, N. H., Shirazi, S. M., Ibrahim, N. F. B. & Baloo, L. (2016). Effectiveness of water quality index for monitoring Malaysian River water quality. *Polish Journal of Environmental Studies*, *25(1)*, pp. 124-129.

Ng, C. K. (2017). Agriculture and water pollution risks. *UTAR Agriculture Science Journal*, *3*, pp. 34-44.

Ngabirano, H., Byamugisha, D. & Ntambi, E. (2016). Effects of seasonal variations in physical parameters on quality of gravity flow water in Kyanamira Sub-County, Kabale District, Uganda. *Journal of Water Resource and Protection*, *8(13)*, pp. 1297-1309.

Ngadiman, N., Bahari, I., Kaamin, M., Hamid, N. B., Mokhtar, M. & Sahat, S. (2016). Water quality of hills water, supply water and RO water machine at Ulu Yam Selangor. *IOP Conference Series: Materials Science and Engineering*. pp. 1-7.

Ngah, M. S. Y. C. & Othman, Z. (2012). Impact of land development on water quantity and water quality in Peninsular Malaysia. *Malaysian Journal of Environmental Management*, *12(2)*, pp. 113-120.

PTTAUTHM PERPUSTAKAAN TUNKU TUN AMINAH

Nithyanandam, R., Huan, T. W. & Thy, N. H. T. (2014). Case study: Analysis of water quality in Sungai Batu Ferringhi. *Journal of Engineering Science and Technology, EURECA*, 15-25.

Pandit, M., & Paudel, K.P. (2016), Water pollution and income relationships: A seemingly unrelated partially linear analysis, *Water Resources, 52*, pp. 7668-7689.

Patra, J. C. & Bornand, C. (2010). Nonlinear dynamic system identification using Legendre neural network. *International Joint Conference on Neural Networks (IJCNN)*. IEEE. pp. 1-7.

Pires, N., Muniz, D., Kisaka, T., Simplicio, N., Bortoluzzi, L., Lima, J. & Oliveira-Filho, E. (2015). Impacts of the urbanization process on water quality of Brazilian Savanna Rivers: The case of Preto River in Formosa, Goias State, Brazil. *International Journal of Environmental Research and Public Health, 12(9),* pp. 10671-10686.

Rahaman, Z. A., Farhana, S., Rus, C. H. E., Omar, M. A. & Ismail, W. A. N. R. (2016). Rivers and Lakes as Natural Heritage : Water quality status in the Northern States of Peninsular Malaysia, *The Asian Journal of Humanities, 23,* pp. 109-128.

Rani, S. & Parekh, F. (2014). Application of artificial neural network (ANN) for reservoir water level forecasting. *International Journal of Science and Research*, *3(7)*, pp.1077-1082.

Rao, V. (2013). A classical way of finding water pollution by using artificial neural network. *School of Computing Science and Engineering, 3(3),* pp. 449-457.

Razelan, F. M., Tahir, W. & Yahaya, N. K. E. (2018). Studies on the current state of water quality in the Segamat River. *IOP Conference Series: Earth and Environmental Science*. IOP Publishing. pp. 12-16.

Read, E. K., Carr, L., De Cicco, L., Dugan, H. A., Hanson, P. C., Hart, J. A. & Winslow, L. A. (2017). Water quality data for national-scale aquatic research: The water quality portal. *Water Resources Research*, *53(2),* pp. 1735-1745.

Rosman, P. S. (2015). Water Quality Assessment of Muar River Using Environmetric Techniques and Artificial Neural Networks. *Proceeding of Engineering Technology International Conference*, pp. 10-11.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Sage, J., Bonhomme, C., Al Ali, S. & Gromaire, M. C. (2015). Performance assessment of a commonly used "accumulation and wash-off" model from long-term continuous road runoff turbidity measurements. *Water Research, 78*, pp. 47-59.

Sakizadeh, M. (2015). Assessment the performance of classification methods in water quality studies: A case study in Karaj River. *Environmental Monitoring and Assessment*, *187(9),* pp. 573-580

Saravanan, K. & Sasithra, S. (2014). Review on classification based on artificial neural networks. *International Journal of Ambient Systems and Applications (IJASA), 2(4),* pp. 11-18.

Sarkar, A. & Pandey, P. (2015). River water quality modelling using artificial neural network technique. *Aquatic Procedia*, *4,* pp. 1070-1077.

Sharma, A. & Chopra, A. (2013). Artificial neural networks: Applications in management. *IOSR Journal of Business and Management, 12(5),* pp. 32–40.

Sheela, K. G. & Deepa, S. N. (2013). Review on methods to fix number of hidden neurons in neural networks. *Mathematical Problems in Engineering*, *2013*.

Siwar, C., Ahmed, F., Bashawir, A. & Mia, S. (2016). Urbanisation and urban poverty in Malaysia : Consequences and vulnerability. *Journal of Applied Sciences, 16(4),* pp. 154-160.

Sohaili, J., Kasan, N. A., Ibrahim, Z. & Hashim, N. (2014). The Integrated Biological Indicator As A Tool For Detection Of River Pollution. *Brunei International Conference on Engineering and Technology,* pp. 1-9

Solaimany, A. M., Maleki, A. & Hadi, M. (2013). Application of artificial neural network (ANN) for the prediction of water treatment plant influent characteristics. *Journal of Advances in Environmental Health Research*, *1(2),* pp. 89-100.

Sultana, T., Haque, M. M., Salam, M. A. & Alam, M. M. (2017). Effect of aeration on growth and production of fish in intensive aquaculture system in earthen ponds. *Journal of the Bangladesh Agricultural University*, *15(1),* pp. 113-122.

Sumathi, S. & Paneerselvam, S. (2010). *Computational Intelligence Paradigms: Theory & Applications using MATLAB*. 1st ed. CRC Press.

Swain, M., Dash, S. K. & Mohapatra, A. (2012). An approach for Iris plant classification using neural Network. *International Journal on Soft Computing (IJSC), 3(1),* pp. 79–89.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Talib, A. & Amat, M. I. (2012). Prediction of chemical oxygen demand in Dondang River using artificial neural network. *International Journal of Information and Education Technology*, 2(3), pp. 259-261.

Taner, M. Ü., Üstün, B. & Erdinçler, A. (2011). A simple tool for the assessment of water quality in polluted lagoon systems: A case study for Küçükçekmece Lagoon, Turkey. *Ecological Indicators*, *11(2)*, pp. 749-756.

Thair, S. K., Hameed, M. J. A. & Ayad, S. M. (2014). Prediction of water quality of Euphrates River by using artificial neural network model (spatial and temporal study). *International Research Journal of Natural Sciences, 2(3)*, pp. 25-38.

Than, N. H. (2017). Water quality classification by artificial neural network: A case study of Dong Nai River, Vietnam. *Vietnam Journal of Science and Technology*, *55(4)*, pp. 297-303.

Tyagi, S., Singh, P., Sharma, B. & Singh, R. (2014). Assessment of water quality for drinking purpose in District Pauri of Uttarakhand, India. *Applied Ecology and Environmental Sciences*, *2(4)*, 94-99.

US Environmental Protection Agency. (2013). *Aquatic Life Ambient Water Quality Criteria for Ammonia-Freshwater.*

Uwidia, I. E. & Ademoroti, C. M. A. (2011). Characterisation of domestic sewage from an estate in Warri, Nigeria. *International Journal of Chemistry*, *3(3)*, pp. 81-86.

Verma, N. & Singh, A. K. (2013). Development of biological oxygen demand biosensor for monitoring the fermentation industry effluent. *ISRN Biotechnology*, pp. 1-6.

Walters, S. P., Thebo, A. L. & Boehm, A. B. (2011). Impact of urbanisation and agriculture on the occurrence of bacterial pathogens and stx genes in coastal waterbodies of central California. *Water Research*, *45(4)*, pp. 1752-1762.

Wang, W., Yang, Z., Kong, J., Cheng, D., Duan, L. & Wang, Z. (2013). Ecological impacts induced by groundwater and their thresholds in the arid areas in northwest China. *Environmental Engineering & Management Journal*, *12(7)*, pp. 1497-1507.

Wechmongkhonkon, S., Poomtong, N. & Areerachakul, S. (2012). Application of artificial neural network to classification surface water quality. *World Academy of Science, Engineering and Technology*, *6(9)*, pp. 574-578.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Yan, C. A., Zhang, W., Zhang, Z., Liu, Y., Deng, C. & Nie, N. (2015). Assessment of water quality and identification of polluted risky regions based on field observations & GIS in the Honghe River Watershed, China. *PLoS ONE, 10(3)*, pp. 1-13.

Yang, X., Kumehara, H. & Zhang, W. (2009). Back propagation wavelet neural network torque signals. *Computer and Information Science, 2(3)*, pp. 75-86.

Yin, Z., Jia, B., Wu, S., Dai, J. & Tang, D. (2018). Comprehensive forecast of urban water energy demand based on neural network model. *Water Resources, 10(4)*, pp. 385-392.

Zabidi, A., Khuan, L. Y., Mansor, W., Yassin, I. M. & Sahak, R. (2010). Classification of infant cries with asphyxia using multilayer perceptron neural network. *Second International Conference on Computer Engineering and Applications, 10(1)*, pp. 204-208.

Zadpoor, A. A., Campoli, G. & Weinans, H. (2013). Neural netowrk prediction of load from the morphology of trabecular bone. *Applied Mathematical Modelling, 37*(7), pp. 5260-5276.

Zeinalzadeh, K. & Rezaei, E. (2017). Determining spatial and temporal changes of surface water quality using principal component analysis. *Journal of Hydrology: Regional Studies*, *13(1)*, pp. 1-10.

Zhang, Z. (2016). Introduction to machine learning: k-nearest neighbors. *Annals of Translational Medicine*, *4*(11), pp. 1-7.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH